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HXN 3ID Radiation Shielding Analysis

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3-ID HXN Beamline Radiation Shielding Analysis	

1. Introduction:

This note documents the radiation shielding analysis of Hard X-ray Nanoprobe (HXN, 3 ID) beamline at 500 mA, including Gas Bremsstrahlung (GB) and Synchrotron Radiation (SR). Figure 1 shows the layout of HXN, which uses an in vacuum undulator (IVU20) source.

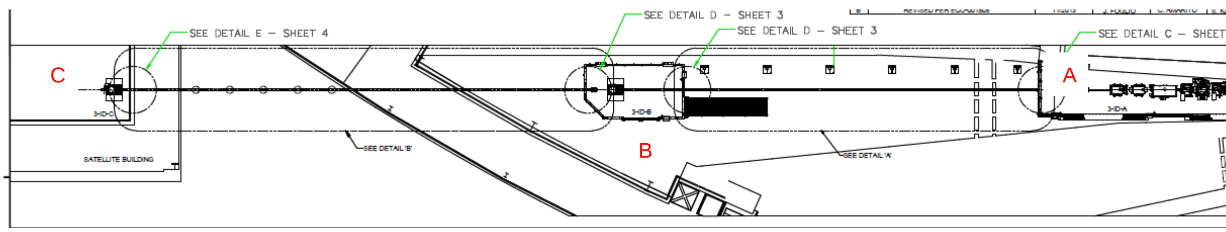

Figure 1 HXN layout

2. GB Shielding Calculation

For the evaluation of the GB shielding requirements, the undulator source is assumed to have a 15.5-m-long air section at 10^{-9} torr. The FLUKA simulation uses a 1/*k* energy spectrum (with *k* denoted as the photon energy) from 10 keV up to 3 GeV [1], and the FLUKA results are normalized to the power of 17 µW, which is the GB source for 3 GeV, 500 mA electron beams at 1 ntorr of Storage Ring Vacuum [2]. The First Optical Enclosure (FOE) shielding is dominated by GB. The FOE lateral panel is made of 18 mm Pb, roof 6 mm Pb and downstream wall 50 mm Pb.

The main scatterers considered in the Secondary Gas Bremsstrahlung (SGB) shielding analysis are: mirror and white beam stop. The HXN FLUKA geometry is shown in Figure 2 and main parameters are listed in Table 1.

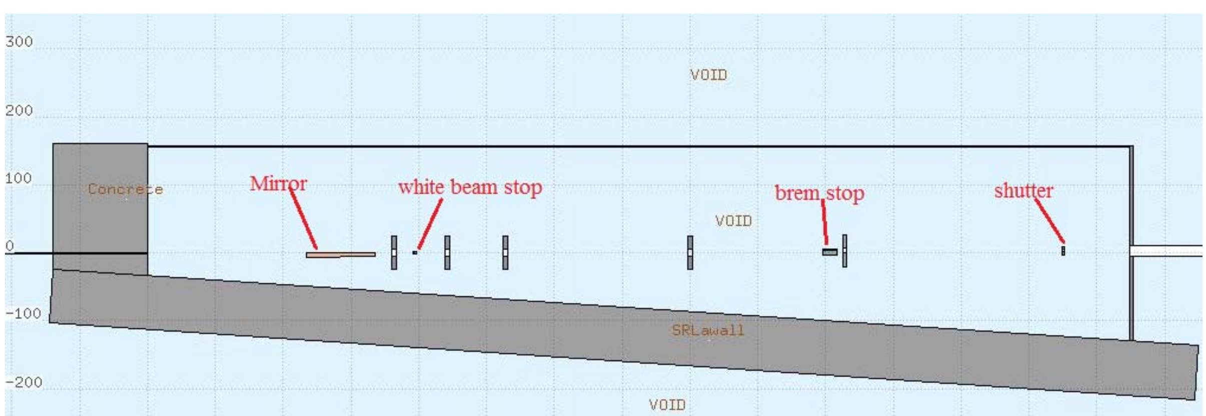

Figure 2 Main scatterers, collimators and shields

Table 1 Z locations and dimensions of main scatterers and shields

Scatterers	Upstream Z location (Distance from straight section center)	Dimensions	Material
Mirror	2785 cm	6 cm × 6 cm × 100 cm L (0.1833 degree incidence angle)	Silicon
White beam stop (followed by 2 cm tungsten)	2938.9 cm	4.6 cm × 1.26 cm × 5 cm L (10 degree incidence angle)	Copper
Shields	Upstream Z location (Distance from straight section center)	Dimensions	
Shield 1	2910 cm	50 cm × 50 cm × 7 cm thick (aperture: 10 cm ×10 cm)	Lead
Shield 2	2988 cm	50 cm × 50 cm × 7 cm thick (aperture: 10 cm ×10 cm)	Lead
Shield 3	3075 cm	50 cm × 50 cm × 7 cm thick (aperture: 10 cm ×10 cm)	Lead
Shield 4	3346 cm	50 cm × 50 cm × 7 cm thick (aperture: 10 cm ×10 cm)	Lead
Shield 5	3576.1 cm	46.75 cm × 46.7 cm × 5 cm thick (aperture: 6.75 cm ×6.7 cm)	Tungsten
Bremsstrahlung Stop	3546 cm	8.95 cm × 5.85 cm × 20 cm thick (aperture: 0.7 cm ×0.5 cm)	Tungsten
Shutter	3898.1 cm	12.5 cm × 15 cm × 3.8 cm thick (aperture: 4 cm × 2.5 cm)	Tungsten

2.1 Mirror as scattering target

HXN has a 1 meter long mirror, which rotates at 0.18 degree to kick beam outboard. With all 5 SGB shields (shield 1 to shield 5 in Table 1) installed, the dose rate in all occupied areas (including downstream of FOE and on surface of beampipe) is < 0.01 mrem/h, as shown in Figure 3. Note only dose rates on beam plane (especially downstream FOE area) are plotted in this note. (The dose rates on the FOE roof and lateral wall are always < 0.05 mrem/h for HXN beamline based on FLUKA calculation, with or without additional SGB shields.)

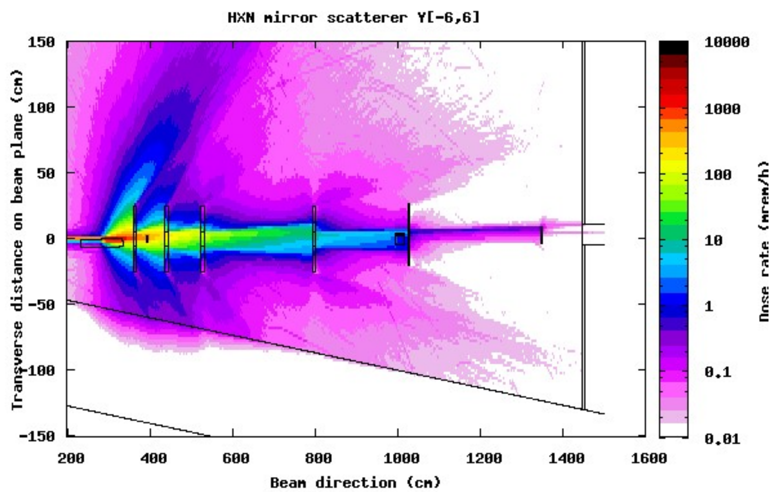

Figure 3 HXN mirror scatterer dose rate on beam plane

Figure 4 shows the dose rate if only shield 5 for SGB scattering (z = 3576.1 cm) is installed. In FLUKA simulation, the first 4 SGB shields were changed to air material, and the dose rate on FOE downstream wall surface is shown in Figure 4.

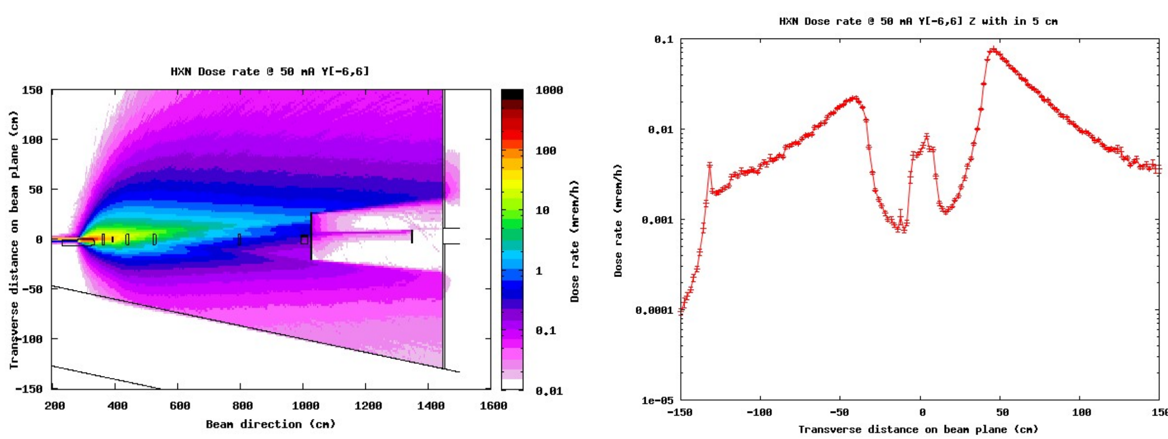

Figure 4 HXN dose rate with only shield 5 installed

Based on FLUKA calculation, HXN is shielded up to 70 mA if shield 1 to shield 4 are not installed (surface dose rate on FOE wall < 0.5 mrem/h, 30 cm dose rate < 0.05 mrem/h, all other shields including SGB shield 5 installed).

2.2 White beam stop as scattering target

White beam stop is a 5-cm copper block rotated by10 degrees (about horizontal axis), followed by 2 cm tungsten. This calculation is for a non-normal scenario since HXN mirror is usually “in” during operation. The dose rates on beam plane is properly plotted in Figure 5.

As shown in Figure 5, HXN is sufficiently shielded at 500 mA with all five SGB shields installed. The dose rate from white beam stop scatterer is < 0.01 mrem/h in all occupied areas.

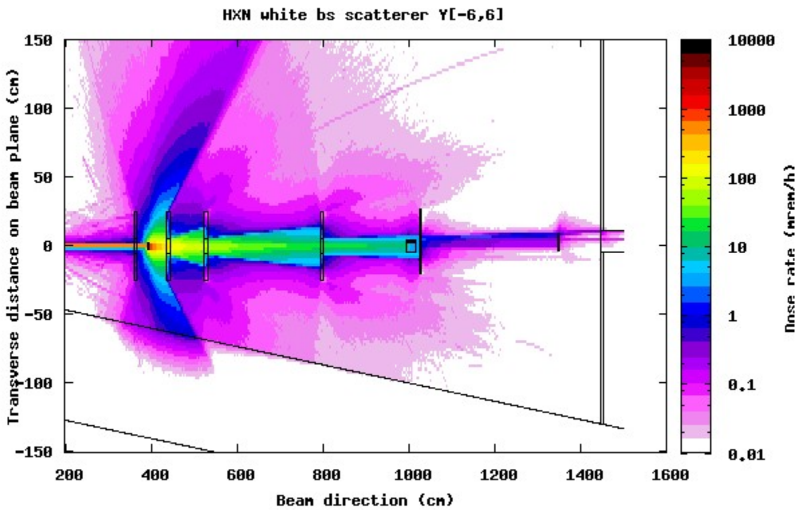

Figure 5 white beam stop scatterer

2.3 HXN Bremsstrahlung stop non-compliance with guideline

HXN has a tungsten bremsstrahlung stop located downstream of FOE. The shielding guideline requires > 24 mm distance between GB extreme ray and the edge of bremsstrahlung stop. However, on one side of the HXN bremsstrahlung stop, the distance is smaller (~22 mm).

The following FLUKA simulation was done: the distance between upstream of the GB stop is 450 cm from FOE downstream wall (the same as HXN beamline). In the simulation, the GB stop size is 30 mm × 30 mm × 20 cm thick. As shown in Figure 6, when a pencil beam (17 µW GB) shoots the block center, the dose rate downstream of FOE is ~ 0.03 mrem/h. In this case, the distance between GB ray and shielding edge is only 15 mm, therefor HXN stop is sufficient to contain all primary gas bremsstrahlung (PGB) mis-steering rays.

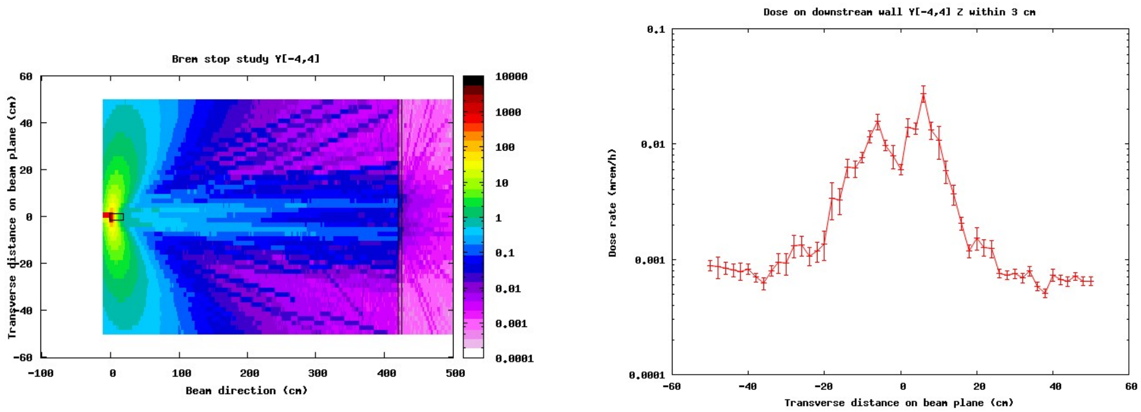

Figure 6 PGB mis-steering ray on bremsstrahlung stop (15 mm distance between mis-steered GB and bremsstrahlung stop edge)

3. SR Shielding Calculation

The HXN beamline is an IVU 20 source and the source parameters are listed in Table 1.

Table 1 Source Parameters for IVU 20 [3]

Source	Max. source opening	No. Of periods	Max. B_{eff} (T)	Period (mm)	E_c (keV)	Total power (kW)
IVU 20	1.0 mrad-H	148	1.03	20	6.65	9.4

3.1 FOE wall / roof for white beam

The FOE shielding is dominated by GB. The dose rate from SR is negligible on lateral wall, roof and downstream wall with current FOE shielding.

3.2 Transport pipe and monochromatic hutches

The HXN transport pipe is wrapped by 3 mm Pb and hutch B is shielded by 6 mm Stainless steel. Hutch C is composed by 10 inch concrete walls on all sides and roof.

HXN has two mirrors and one set of monochromatic crystals to reflect beam to transport pipe and mono hutches (B and C). The IVU 20 fundamental energy is 1.6 keV at minimum gap of 5 mm. The operation energy is from 5 to 30 keV.

STAC8 calculation was done for the maximum mono energy (30 keV with 3.9 eV bandwidth). For the worst case (two mirrors are platinum coated at 0.172 degree), the dose rate is negligible (< 0.001 mrem/h) outside of transport pipe and hutch enclosures.

4. 50 mA commissioning analysis

This session analyzes the size of a needed exclusion zone for 50 mA commissioning if none of the SGB shields is installed (Shield 1 to shield 5 in Table 1). Figure 7 shows the 2-D dose rate at 50 mA without SGB shields (mirror scatterer). In FLUKA simulation, the material of all 5 SGB shields was changed to air.

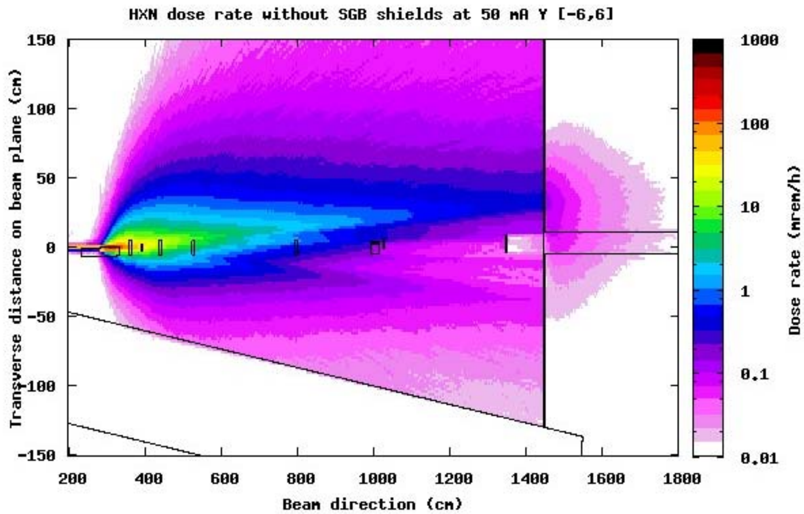

Figure 7 HXN dose rate without SGB shields at 50 mA

As shown in Figure 7, a 2-m long exclusion zone downstream of FOE (+/- 1 meter around beam center) is needed for 50 mA commissioning if no SGB shields installed for HXN.

5. Conclusions:

For 500 mA operation, with all five SGB shields installed (shield 1 to shield 5 in Table 1), the HXN radiation level meets NSLS-II shielding policy.

1) The dose rate in all occupied areas is < 0.05 mrem/h.

HXN is shielded for 50 mA commissioning if first four SGB shields (shield 1 to shield 4 in Table 1) are not installed (all other shields in place including shield 5). All the SGB shields must be installed before the current goes up.

If none of the five SGB shields exists, a 2-m long exclusion zone (+/- 1 meter around beam center) downstream of FOE is needed for 50 mA commissioning.

There may be small deviations between the reality and FLUKA model. For example the last SGB shield 5 will be shifted (~0.5 m) downstream due to practical difficulty. Based on review, this deviation will not change the dose rate significantly. Also shield 5 is changed from tungsten (in FLUKA model) to Pb in reality (with equivalent thickness), which is not decreasing shielding effectiveness either. All shielding will need to be verified by radiation survey during commission. If a radiation leakage is observed during the measurement, shielding shall be installed to mitigate the radiation level outside of the enclosure to acceptable level.

Reference:

[1] J.Donald Cossairt, Fermilab-TM-1834, Radiation Physics for Personnel and Environmental Protection, Revision 11, November 2011.
[2] P.K. Job, Shielding Guidelines for Secondary Bremsstrahlung at NSLS-II Beamlines with Mirror as the First Optical Element, September 11, 2012.
[3] P.K. Job, LT-C-ESH-STD-001, Revised Guidelines for the NSLS-II Beamline Shielding Design, September 17, 2013.